THE INSTITUTE OF PHYSICS
47 BELGRAVE SQUARE, LONDON, S.W.1.

BULLETIN

No. 46 OCTOBER, 1953

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RESEARCH ASSOCIATIONS

III — THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION: PHYSICS IN IRON AND STEEL MANUFACTURE

By M. W. THRING, M.A., F.Inst.P.*

THE PROCESSES OF IRON AND STEEL MAKING

The business of the iron and steel industry is to make, on the one hand, pig iron for remelting by the iron casting industry and, on the other, mechanically shaped steel for all purposes of the engineering industries. The raw materials for pig iron manufacture are primarily iron ore and coke, and for steel manufacture, pig iron (molten or frozen) and scrap steel. The main processes are thus chemical reduction of oxide, melting, removal of impurities and plastic deformation.

The manufacture of pig iron is essentially the reduction of the iron oxide by means of carbon in the form of coke, the heat for the reaction and fusion coming from partial combustion of the coke with preheated air. Limestone and other suitable materials are used to flux the excess of silica present in the ore; the resulting slag is separated from the fused iron by gravity. The molten iron thus obtained contains a comparatively large amount of metallic and non-metallic impurities. The necessary time of contact between the reducing gases and the ore is obtained by using a very large vertical furnace (the blast furnace, Figs. 1 a. and 1 b.) up which the gas is blown and down which the solids and liquids travel. Ideally the gas flow up this shaft and the particle flow down should be perfectly uniform to give the greatest possible time of contact.

The making of steel ingots from the pig iron and scrap is mainly carried out in the regenerative open hearth furnace (Fig. 2) in which the heat for melting is supplied to the bath by a long flame of gas or liquid fuel burnt with highly preheated air. The refining process is a controlled oxidation of the impurities by oxygen coming from the flame (air) or from iron oxide in a molten slag floating on the molten metal. To remove sulphur it is necessary to make the slag basic by the addition of lime. The steel is made with carbon contents varying usually from 0 to 1% according to the purpose, and various proportions of alloying elements such as chromium, nickel, vanadium and tungsten are added to improve such properties as strength, chemical resistance, etc. When the steel has reached the required temperature and composition it is tapped from the furnace into a ladle and cast into ingots in cast iron moulds. This freezing involves, besides the ordering of the crystal lattice and the growth of the crystal

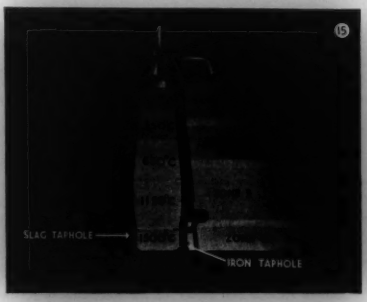

Fig. 1a. Blast Furnace.

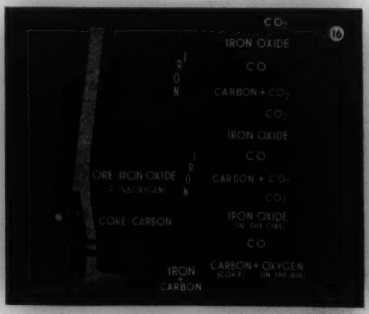

Fig. 1b. Reactions in the Blast Furnace.

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aggregates, the segregation of small amounts of metallic and oxide impurities and the evolution of gases within the metal.

The steel ingots are then heated and mechanically deformed; the greater part go through a series of hot and cold rolling processes to produce plates, sheet, strip, rod, wire and girders, but others are forged, hammered, pressed and drawn through

Fig. 2. Open Hearth Furnace.

dies and now even extruded. Besides the change of external shape these processes produce rearrangement of the crystals and of the impurities and various degrees of disorientation in the individual crystal lattice. Heat treatment cycles are used in some cases to modify further the crystal size and physical properties of the steel. In other cases rapid cooling is used to produce metastable structures. The hardness and stability can be further modified by subsequent reheating to a lower temperature, followed by a slow cooling.

THE ORGANIZATION OF THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION

To study the bases of these processes and the possibility of replacing the apparatus in which they are carried out by more efficient apparatus, the British Iron and Steel Research Association has been established with five divisions corresponding to five stages of steelmaking, and two departments dealing respectively with the physics and chemistry underlying the processes ; there is also an operational research section.

The Ironmaking Division is concerned with the treatment of iron ore to prepare it for the blast furnace, the processes in the blast furnace and the production of frozen or liquid pig iron. The primary objective of this Division is to reduce the consumption in the blast furnace of coke which must necessarily be an expensive fuel as it has to be mechanically strong and in large lumps to provide a permeable freely-moving bed ; the use of cheaper fuel to pretreat the ore is thus a promising line of development. Secondary objectives are to produce purer iron in spite of the trend to the deterioration of ore quality, without increasing the coke consumption. Many alternatives to the blast furnace which would not require hard coke are examined.

The Steelmaking division takes over the field of study from the stage of the molten pig iron which passes with steel scrap into the open-hearth furnace, and its rivals the Bessemer converter and the electric arc and high frequency furnaces, and continues as far as the casting of the molten steel into ingots. Its objectives are to increase output per unit of plant, to reduce the consumption of all the raw materials used to make a ton of steel—fuel, metallic materials, fluxes, and refractories, and to improve the quality of the ingots. These can be achieved by finding out the best designs and materials for the furnaces, the best way to operate them, sometimes by adding auxiliary equipment for accelerating processes and for measurement, and by investigating new processes.

The Mechanical Working Division investigates the processes of rolling, forging, wire drawing and coating steel, with the objectives of reducing the power requirements, producing a more accurately shaped product having a more controlled texture and reducing the wear on the shaping tools. To do this the deformation flow patterns and frictional losses must be understood, the parameters of the process such as forces and displacements and internal weaknesses measured and new shapes and arrangements of deforming systems tested.

The Metallurgy Division studies the structure and properties of steels as functions of their heat and mechanical treatment and composition. This structure is related to its mechanical strength under various conditions such as impact over a range of temperatures (brittle fracture), long time loading and high temperatures for power plant steels (creep), repeated loading for ball bearing and spring steels (fatigue), and to other physical properties such as magnetic hysteresis (for transformer core steels).

The Plant Engineering Division is concerned with the design and layout of the actual structures and machines used for the processes of the steelworks. Its objectives are to know more about the actual demands made on the units in order on the one hand to enable them to be built with smaller factors of safety and on the other to lengthen the lives of the components and reduce breakdowns.

It is also concerned with the transport of raw materials to the works, of solid and liquid metal and other materials from one process to another, and of finished products away from the works, the object being to ensure that the most appropriate methods of handling are used in the most efficient manner.

The Physics and Chemistry Departments have the dual role of studying the chemical and physical relations underlying the processes of the Divisions and of observing the potentialities of new lines of research starting at the universities for assisting the problems of the steel industry. Their work is thus largely carried out on behalf of the Divisions.

The Chemistry Department is especially concerned with studying the equilibria and kinetics of the complex high temperature reactions which take place between metals, elements in the metal, combustion gases and slag in the blast furnace, steelmaking processes and transport ladles. It has also sections which deal with refractories and corrosion. The Corrosion Section studies the degree of protection afforded to iron and steel by various surface treatments when exposed to the influence of the atmosphere, of immersion in fresh or sea water and of burial in soil under conditions which range from arctic to tropical and from industrial to rural.

The next section is a fuller discussion of the work of the B.I.S.R.A. Physics Department.

B.I.S.R.A. PHYSICS DEPARTMENT

General Physics Section

The General Physics Section is concerned with applying the results of dislocation theory to the problems of ferrous metallurgy and with the physical processes involved in the freezing of liquid steel especially moving relative to the mould (continuous casting). The difficulty of applying the simple

dislocation theory to steel lies in the complicating factors of the segregation of different atoms on the grain boundaries, the presence of interstitial elements especially carbon and nitrogen, the intermixture of different types of lattice and the presence of macroscopic oxide inclusions. The metallurgist has an extensive empirical knowledge of the effects of these factors on the bulk strength but much remains to be done before this is placed on a sound theoretical basis.

A number of projects have been carried out by the General Physics Section and by the Metallurgy Division in this field. X-ray diffraction with a Geiger counter has been used to watch transformations as they occur and to investigate the possibility of analysing alloy steel specimens by measuring fluorescent radiation. The damping capacity of a steel wire measured while it was being austenitised was found to depend on the austenite grain size and not on carbon diffusion.

The rate of deformation under load at temperatures up to 1400°C has been measured for steel wires with various carbon contents (Fig. 3). These measurements serve both to test a

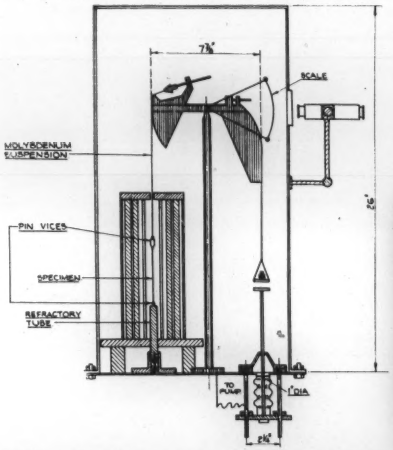

Fig. 3. Vacuum Chamber Furnace and Constant Stress Device.

theory based on the concept of a flow rate equal to the rate of thermal diffusion of dislocation-blocks and to provide numerical data for the calculation of the behaviour of the thin frozen crust of metal under the strain of continuous casting.

The study of continuous casting is based upon the advantages that would arise if liquid steel could be cast straight into rods, tubes or sheets. An attempt is being made to understand the physical processes of heat transfer to the water-cooled mould of freezing in the crust and flow of the liquid metal in order to establish the limiting casting rate. This laboratory work is leading to the design of plant for highly alloyed steels, usually melted in relatively small quantities.

Fuel Technology Section

Heat transfer, temperature measurement and flame physics are subjects with an essentially physical character studied by the Fuel Technology section. All four methods of heat transfer, forced and natural convection, conduction and radiation are important in steel furnace heating. However, reasonably accurate calculation of forced and natural convection in nearly all cases is possible because the success of similarity theory enables coefficients obtained from models to be applied to a wide range of shapes. Hence the most important problems are those of radiation and of conduction in awkward shapes, in materials having temperature-varying thermal properties and in the unsteady state.

The thermal conductivities and specific heats of a range of steels have been determined by the National Physical Laboratory and those of refractories by the N.P.L. and the British Ceramic Research Association and ingenious applications of electrical analogues, mechanical computers and numerical approximation have been made to the problems of ingot freezing and reheating in B.I.S.R.A. and elsewhere. A thermal model on a 1/50 linear scale but a 1 : 1 temperature scale has been constructed of some materials used in the hearth and foundations of blast furnaces (Fig. 4) and gives the time-temperature relations at various points in the hearth on a time scale of 1/2500. As yet unsolved however are the cases of three-dimensional heat transfer in the freezing of an ingot of finite length and of the full heat balance of a flame-heated furnace.

The non-luminous radiation resulting from the infra-red emission of the triatomic molecules CO_2 and H_2O is well understood theoretically and empirical formulae have been derived for calculating the heat transfer from fully burnt gases. These band spectra do not however make the gases radiate more than about 30% of a full radiator at the same temperature however thick the layer. A higher heat transfer

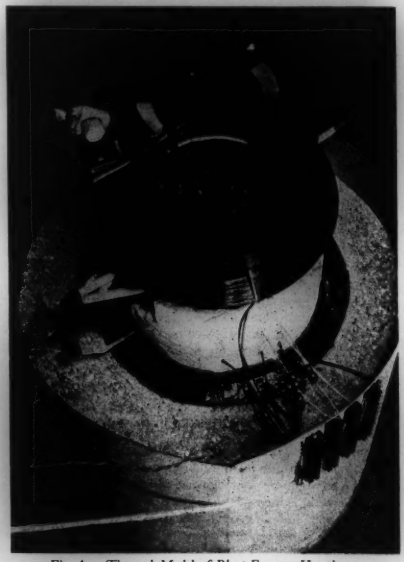

Fig. 4. Thermal Model of Blast Furnace Hearth.

coefficient can be obtained if soot particles can be formed during combustion. The study of the extent to which combustion must be delayed to obtain a given degree of luminosity must be carried out on large scale flames because the interrelation of mixing, heat transfer and combusion cannot adequately be scaled down. This is being done by the International Flame Radiation Committee which is actively supported by B.I.S.R.A.

For this work a narrow angle total radiation pyrometer has been developed using a front plated mirror to focus all wavelengths equally, and methods of measuring the soot size *in situ* by the polar diagram of scattered u.v. light have been sought.

The measurement of the temperature of liquid steel in the open hearth furnace is obviously vital to the control of heating and chemical reactions. The platinum-platinum rhodium quick immersion thermocouple was developed in this country by Schofield and Grace of the N.P.L. The use of oxygen lancing to accelerate carbon reduction has introduced a need for measuring temperatures above 1700°C and a tungsten-molybdenum couple has been used for measuring temperatures as high as 1850°C.

Surface temperatures of slabs and ingots in the air and in reheating furnaces are being measured by using a hemispherical reflector to convert the surface into a black body and thus eliminate emissivity corrections.

Aerodynamics Section

The efficiency and continuity of a number of steel-making processes depends upon achieving the right fluid flow pattern in cases including :

(i) Combustion gases in the open-hearth furnace ; here the objectives are to transfer heat as rapidly as possible to the bath and as slowly as possible to the refractories, to control fuel and air mixing and to use as much of the heating surfaces of the regenerators as possible ;

(ii) Flow of liquid steel inside the furnace, through runners and into moulds ; inside the furnace the objective is to accelerate steel/slag reactions, in the runner and moulds to minimise spashing ;

(iii) Gas flow distribution up the shaft of the blast furnace ; the objectives are to obtain uniform distribution and minimum pickup of solids in the gas stream ;

(iv) The flow of cooling water in parts of furnaces that must be cooled, such as door frames and blast nozzles ; by obtaining a good distribution the necessary water flow can be greatly reduced ;

(v) The relation between gas and particle flow in gas cleaning problems.

The small scale cold air or water model with Reynolds similarity has proved to be a most valuable tool for the first problem. Four techniques have been employed for the use of the air model for quantitative measurements. These are :

(i) the pitot static tube for measurement of direction and velocity of flow ;

(ii) the use of a small quantity of methane or butane as a mixing tracer combined with samples taken off to an infra-red gas analyser ;

(iii) the use of fine Balsa wood dust to give visualisation of the flow pattern, and

(iv) a dust deposition technique for studying erosion patterns. The technique is now being used in the attempt to determine what is the right shape for the end of an open-hearth furnace ; here the outgoing gases have to be deflected through a right angle and can easily cause very severe erosion.

These cold models have shown that with the type of flame which occurs in an open-hearth furnace the mixing of the air and fuel primarily takes place as a result of entrainment of relatively slow moving air by the turbulent drag due to the momentum of the high velocity fuel jet. This has led in turn to the conception of the efficiency of an open hearth furnace steam-borne oil burner as the ratio of the jet momentum which it produces to that which could be produced if all the compression energy of the steam were used in providing momentum for the steam and the oil together. Measurement of the thrust of an oil burner of this type gives its efficiency.

Fig. 5. Hot Wind Tunnel.

For the measurement of flow patterns within actual furnaces it is necessary to use a water-cooled pitot static tube and this raised the question of whether such a tube calibrated with the tube and the surrounding air cold, will have the same co-efficient when the tube is used cold with a hot gas. A special hot wind tunnel (Fig. 5) has been built and with one type of pitot tube the coefficient has been found to be altered. Water models have been used to study splashing effects in the teeming of ingots.

Instrument Section

Instruments have been developed in B.I.S.R.A. and in the laboratories of the steel companies in the last few years for measuring and controlling processes in the industry by magnetic, electronic, optical and mechanical means.

Permeammeters for strips of transformer sheet steel have been developed by B.I.S.R.A., Guest, Keen and Nettlefolds Ltd. and Colvilles Ltd. A gauge for measuring the thickness of mild steel plate accessible on one side only measures the saturation magnetic flux between a central and a concentric annular pole piece.

A null-balance electronic meter for measuring and controlling the gas pressure inside an open-hearth compared to atmospheric can be placed on the furnace roof and so eliminates errors in pressure lines. A similar electromagnetic balancing principle has been applied in the Quick Acting Balance developed to speed up routine weighing. This also uses cross spring hinges to eliminate knife edge wear. A very interesting study is the effect of non-ferrous coating thickness, surface carburisation and other metallurgical variables on the resistance and inductance at various high frequencies of a search coil placed near a steel surface. By the help of a mixture of simplified theory and direct empiricism it is possible to find conditions under which the system can give a direct indication of the metallurgical condition of the surface.

Mathematics Section

There are two ways in which the experimental work requires to be supplemented by mathematical specialists, namely :

(1) the solution of the differential equations involved in applying various theoretical assumptions to make a model of the empirical system ; and

(2) the statistical design and evaluation of the experiments.

A blast furnace, an open-hearth furnace or a fatigue specimen is severely affected by a number of variables other than those which can be controlled. Hence it is necessary to apply the methods of analysis and experiment design which have been developed by the biologists to these industrial plants. The first steps in the case of the open-hearth furnace were to record the output variables for a large number of casts together with as many of the input variables as could be measured on one furnace and carry out a multiple regression analysis and to compare the mean values of the output variables for a number of casts on each of a series of different furnaces. The second step was to persuade the plant operators to allow certain variables to be controlled at high and low values in a systematic factorial experiment. Three such trials have been carried out each with partial success so that it is becoming possible to lay down the conditions for a profitable trial of this type. The third step is the measurement of the instantaneous values of certain internal conditions of the system such as flame radiation intensity and chemical reaction speed while some of the external variables are changed over short periods. The final step will be to include rebuilding the shape of the furnace structure as a variable in a comprehensive factorial experiment since the effect of design has never been determined independently of a large number of other alterations.

In theoretical physics the work of the section has included the solution of the differential equations for heat flow by conduction in freezing steel, by conduction and convection in regenerative heat exchangers, and also by radiation in other metal and refractory systems ; the equations for turbulent diffusion, stochastic equations for such systems as ore storage, and statistical fluctuations in X-ray counting.

SOME APPLICATIONS OF PHYSICS IN STEELWORKS' LABORATORIES

For the sake of continuity a number of examples of physical research in the steelworks' laboratories have already been mentioned because they interlocked with work in B.I.S.R.A. Besides these examples however much other work is proceeding in the research laboratories of steel companies.

In the first category can be placed the measurement by physical methods of the solidity of steel shapes. Radiography using γ-ray emitting isotopes, hard X-rays from high voltage sets up to 1½ million volts and even from higher effective voltages obtained in synchrotons is being used in the industry for detecting internal flaws in castings, tubes, slabs and welds. Ultrasonic reflection and absorption also play a part in this objective. A sonic method has been used for determining Young's Modulus of refractory bricks.

Physical properties of steel which are being measured to relate them to metallurgical structure include co-efficients of expansion, magnetic properties, electrical resistance and elastic moduli specific heat and latent heats. X-ray diffraction is in use at many works both for routine study of metallurgical structure and for research on the preferred orientation heat treatment and alloy structure. Microradiography has been used to investigate inclusions. At least one steel company makes regular use of an electron microscope on replicas of etched surfaces for the resolution of very fine structures.

CONCLUSION

These notes give some indication of the wide variety of ways in which the steel industry needs the method of thinking and the experimental techniques of the physicist. It is clear, however, that only the fringe of the possible range of subjects has been touched so far. The development of satisfactory physical pictures of the freezing, transformation and deformation processes in the complex steel material, of the combustion and radiation processes in flames, and of turbulent mixing and flow patterns in gases will make big contributions to the practical methods used in the industry, and the introduction of instruments to measure all the important physical variables of the steelmaking systems will provide control at all stages.

PHYSICAL SOCIETY MEETINGS

Members of the Institute are invited to attend any of the following meetings of the Physical Society and its groups.

Date	*Title*	*Lecturer*	*Place*
Oct. 23, 5.00 p.m.	Chree's Influence on Present-Day Geophysics (Charles Chree Medal and Prize)	Prof. J. Bartels	London : Science Museum
Nov. 4, 3.30 p.m. Colour Group	Visual Purple.	Dr. W. A. H. Rushton Dr. R. A. Weale	London : Institute of Ophthalmology
Nov. 12, 2.30 p.m. Optical Group	The Latent Period of Vision and the Pulfrich Effect	Dr. G. B. Arden	London : Institute of Ophthalmology
	Discussion on Binocular Vision	Dr. R. A. Weale Prof. W. D. Wright Dr. D. Gabor Mr. R. J. Spottiswoode	
Nov. 12, 5.15 p.m. Acoustics Group	The Measurement of Very Weak Sounds and their Relation to Living Room Conditions	Mr. O. O. Mason Mr. F. H. Brittain	London : Imperial College

Members of the Institute are also invited to attend a meeting of the Institution of Electrical Engineers on Thursday, November 12, at 5.30 p.m. (tea at 5.00 p.m.). Mr. H. W. Swann, and Dr. W. Grey Walter, will open a discussion on " Safety Precautions in Electronic Apparatus with particular reference to Medical Applications."

SCIENCE TEACHERS IN SCHOOLS

(In June, 1953, the Science Masters' Association and the Association of Women Science Teachers issued a report on the results of an enquiry into conditions affecting the teaching of science in grammar schools. Two Fellows of the Institute, one of them a schoolmaster, have written their purely personal comments on the report.)

This Report analyses the replies from 980 Grammar Schools (57 per cent of those circularised) to a recent questionnaire on the conditions under which Science teaching is at present being carried on.

First, the present position is compared with that in 1939. Before the war, the number of schools with more than 25 pupils taking Science in the Sixth Form was 111 ; the number now is 347, a three-fold increase. But in some 376 schools the ratio of Science graduates to the total staff has decreased. More than 10 per cent of Science teaching is undertaken by non-graduates or graduates in other subjects. There are 115 unfilled posts ; 84 cases where parts of science departments have been closed for lack of staff ; and during the last ten years some 975 Science teachers have left the profession to take up other work. Only 25 schools have laboratory assistance up to the standard recommended by the S.M.A., and if the standards of the Science Technologists' Association are used as a guide the number of schools with satisfactory laboratory assistance is even fewer.

On the face of it, it is an extraordinary situation ; if Science teaching were a picturesque craft dying for want of customers, or a rural industry supplanted by mechanisation, the whole country would be seething with schemes for its preservation. But as merely the corner-stone of all higher education in science, and indeed of our future wealth and welfare as a nation, it seems to be decaying without any serious steps being taken to avert such a disaster. The position has worsened in the past two years, for in 1951 the number of male graduates entering the profession was " probably only just sufficient " to make good the ordinary wastage—but they did enter. And it will get worse, for the Report of the Advisory Council on Scientific Policy stated in 1952 that a considerable increase in the number of grammar-school pupils is expected in the next five to ten years, and that some 400 *additional* science teachers per year, in excess of normal wastage, will then be required. Eighteen months have passed since the possibility of taking special measures to increase the numbers of science teachers was foreshadowed in that document.

The main body of the S.M.A. Report consists of selected comments from some 320 schools. Replacements are not forthcoming, and if available are of poor quality ; " absurd " applications, and even the desperate appointment of " hopeless " teachers, and men who had frankly failed in other walks of life ; twenty changes in one post in six years. These are typical comments. One case, which speaks of the depths of despair, was the appointment of a Chemistry specialist who was " entirely without knowledge of the subject." Headmasters doing double duty and men beyond the normal retiring age are filling many of the gaps, and existing staff are shouldering extra work ; but how long can this go on? " Four of my science teachers are 57, and I do not know what will happen if all retire at 60. Application has been made to Governors for some form of Laboratory assistant, application turned down as unnecessary." Several schools comment on the fact that no pupils will consider science teaching as a future career. Two cases are recorded of special responsibility allowances being reduced during the year by local authorities ; even in the present crisis the science master must be reminded that he is a burden on the rates !

As a schoolmaster, I have some comments to add. The cost of living is high for everybody, nobody expects to regain the standards of 1939 or would wish to while others go short, and grammar school salaries are not inadequate to support life. But they are unattractive, becoming more so as a man gets older. Teaching is surely the only profession in which hard and devoted work receives the same financial reward as indifferent or even negligent performance. This is bad business, and worse psychology. Would any business, recognising that it was in a seller's market, hope to recruit staff by offering an unattractive salary scale with a maximum reached not at the peak of a man's usefulness, but just at the time when he becomes too old to move elsewhere ? If the whole salary structure were recast in a much more generous spirit which reflected an appreciation of good work and good men, teaching would be more likely to get and to keep its fair share of them. There are many to whom the work means more than the money, but even the most altruistic must feel that they are rated cheaply by the community.

But it may be said that improved salary conditions alone are no solution. Obviously we cannot by any means attract people who simply do not exist. This argument, which may well be an excuse for not trying should be examined. It is true that at present the Civil Service and industry can absorb the full output of capable graduates, at least in physics ; but must they ? It has been necessary in emergency to live on our scientific capital, but this is an easy habit to drift along with after the real urgency has been met. Can we believe that, at the present critical stage in the schools, men cannot be spared to ensure the continuance of the species ? The lamentable answer seems to be that we can, accompanied by a little wringing of hands in White Papers, without examining its truth or taking active steps to do something about it. For it is easier to believe this than to face the unwelcome fact that, even if they can be spared to teach they do not want to do so.

It is saddening to find that, even while still at school, nearly all science students are determined not to teach. But for this, the large sixth forms might promise a more hopeful future ; if this intention is universally held, what hope can there ever be ? Can the schools and the schoolmasters do anything about it ? Do we set them an example of the kind of person they hope they will never become ? Is it, as Mr. Birley recently suggested, that science teachers have lost their faith in science, and have too narrow and specialised an outlook ? Schoolmasters must share some responsibility for the position, and show more than mere concern for its improvement. But this report would suggest that the way in which they can honestly be expected to help recruitment is by pressing for better conditions. All the other arguments, that the people do not exist, wouldn't teach if they did, and so on, lead straight back to the one main point—that salaries and conditions are regarded as unattractive. If it were otherwise, they would attract successfully.

So far, the matter has been treated without any approach to reality. The nation has been acting like a man who complains bitterly that he has a lonely and cheerless old age before him, while slowly starving off his children because he won't pay the grocer's bill. It is all the grocer's fault ; if he would only have the decency to cut his prices the future would be bright. This Report shows that the schoolmasters themselves

have no illusions about the situation ; it should disillusion and shock into energetic action the people who are in a position to set about it while there is yet time.

G. R. NOAKES.

This might have been an important and highly persuasive report. It is, in fact, disappointing. It shows little skill in the presentation of statistical data, and could be expected to influence very few except those who already recognize the urgent need for improving the rate of recruitment of competent science teachers to the schools. The numerical information occupies only five pages of the report and is followed by no less than forty-seven pages of selected comments from individual schools.

The eleven tables of statistics are interesting and provide some valuable data but I at least was quite unable to piece together a coherent picture of the staffing position in the schools concerned. A different method of presentation would have increased enormously the usefulness of the data. For example, Table IV gives the number of special responsibility allowances paid to the science staffs as percentages of the total number of allowances paid in the schools concerned. This statistic is, however, of real value only when one knows the proportion of the science staff to the whole staff of a school. Table III, however, gives, instead of the ratio of science graduates to the total staff, only *changes* of this ratio between 1939 and the present time. Table IV thereby becomes almost useless.

Turning to the part of the report consisting of comments from schools, it is difficult to see what the basis of selection could have been and what purpose can be served by the publication of no less than 323 of these "selected comments." They are wearily repetitive and often utterly trivial, verging at times on the meaningless. As an example, "Replacements of the type expected in a school of this type are not forthcoming" is all that is comprised in one "selected comment" and of course conveys little unless one knows the meanings to be attached to "type" in the two contexts. Occasionally an entry is merely fantastic. For example, "I have interviewed a number of University Students with a view to persuading them to take up Science teaching. In every case I was unsuccessful. Those students in their final honours year had already been provisionally engaged for an industrial post under more attractive conditions, e.g. salary, non-contributory superannuation, expenses, use of the firm's car outside working hours." Many industrial physicists would be glad to know the firms offering these conditions.

It is clear from the report that teachers believe that poor salaries represent the major, if not the only, obstacle to satisfactory recruitment. Few of us would disagree that the salaries of at least some schoolmasters need to be increased substantially but it should be remembered that many teachers earn salaries which do not compare too badly with what they could earn elsewhere. Comparisons with industry and the Civil Service are too easily made, often with the assumption that most teachers could have been among the best paid in these other fields. Yet by no means all honours graduates in the Civil Service are graded in the scientific officer class and there are many physicists in industry whose maximum salary will not be much above £1000 a year. The really able physicists, it is true, will earn far more in industry than in the schools but that is because industry usually adopts a salary structure where there are fairly high ratios between the salaries of the good, the bad, and the indifferent. Is a similar salary structure what the teachers want ? Or is it assumed that an increase of salaries, or allowances, designed to attract the good physicist must necessarily carry an increased reward to the rest ? Special allowances at present rarely exceed £150 a year, a recognition of merit, which, compared with industry, is patently absurd. Yet one has the feeling that teachers would not welcome an approach to the salary difficulty along the lines of greater differentiation. All-round increases are usually urged. But why must higher salaries be paid to the very men that the teachers now resent having to appoint, about whom they bitterly complain and who are virtually irremovable in the conditions of security obtaining in the teaching profession? It might be helpful if the teachers' professional organizations would make their attitude clear on this point.

A further and even greater difficulty arises from the uniformity of teachers salaries. To have to raise the pay of historians and classicists, apparently available in adequate numbers and quality at present salaries, on the ground that physicists are scarce, may be necessary and reasonable but it is not a piece of logic which will command wide respect.

It may also be relevant to mention that, if salaries are the basis of the problem, this represents a reversal of a tendency noticeable among most of the community since the war. Among industrial workers a preference for leisure rather than money, once a reasonable wage level has been reached, has been very clear. Teachers, perhaps rightly, become weary of reference to their holidays, but it *is* true that they have twelve or more weeks holiday a year and, if recruitment depended only on such considerations, it might be expected that more physicists of better than average ability would prefer a schoolmaster's salary with twelve weeks holiday rather than an extra £200 or £300 a year (less tax) in industry with only two or three weeks leave.

Is it not possible, however, that salaries play a smaller part in this problem than is commonly assumed? The opportunities for active engagement in research and development work in physics are great nowadays; it would be surprising if most young graduates did not prefer to take up posts of this kind rather than to teach in schools. Teachers perhaps give too little weight to the possibility that young men actually *prefer* research to school-teaching, even, indeed, if some financial loss were involved. The life of the schoolmaster, rewarding as it is to those who have a sense of vocation for it, probably appeals to few, particularly among those who have a real interest in a subject so much alive as is physics to-day. The preference for "doing" rather than teaching is natural and it is arguable whether this should be discouraged.

Another point that is obvious from this report is that schoolmasters think of "qualifications" as identical with university examination results, even for a teacher with many years experience. For advanced work the schools probably require men with good honours degrees, but, for the rest, is the importance which should be attached to this kind of qualification really as vital as the schoolmasters imply ? There are many able (and some distinguished) physicists—some of them among the more highly paid men of industry—who lack the examination qualifications which the schools assume to be essential for teachers of Ordinary level physics. Sixth form teaching apart, is the correlation between effective teaching and the teacher's own success in university examinations as high as would be suggested by those who have contributed to this report ?

Grammar schools have long lived in a world where they could skim the cream of university graduates for their staffs and our educational system may have gained much from this

position. It is still possible for the schools to implement their belief that small boys should be taught Latin declensions by a man with a first class in the Classical Tripos but perhaps the time has come when this attitude of mind must be changed as far as science is concerned. Neither industry nor the Civil service is staffed wholly by honours graduates and if the schools have to face a similar position the loss may be much less than teachers suppose.

The problems raised by the science masters' report are real and urgent. The pity is that, in my view, the teachers give us no lead in moving towards realistic solutions.

NORMAN CLARKE.

APPOINTMENTS VACANT

The inclusion of particulars of a vacancy must not be taken to imply that the Institute necessarily approves of the terms offered or that might be offered. Candidates should satisfy themselves that these are satisfactory, and they may always refer to the Institute for advice.

Kent and Canterbury Hospital, Canterbury, Kent. Physicist (senior grade) required for duty in the Radiotherapy Department of the above hospital. Appointment subject to Whitely conditions. Full particulars of post and duties will be furnished on application to Group Secretary, Central Office, **Nunnery Fields Hospital,** Canterbury.

British European Airways require a **Flight Simulator Supervisor** for their Training Unit at **Northolt,** to be responsible for organization of the Simulator Section. Responsibilities will include ensuring the technical standards of operating staff and correct maintenance of the Simulators, production of operational exercises and advising on future technical requirements. Essential qualifications : Degree in physics or its equivalent ; thorough knowledge of electrical and electronic systems ; sound knowledge of aircraft radio and aircraft operating techniques. Salary in the range £875 — £1175 p.a. Closing date for receipt of applications October 20, 1953. Written applications to Personnel Officer, **Flight Operations, B.E.A.,** Keyline House, **Ruislip,** Middlesex.

A **Graduate Physicist** or **Electrical Engineer** is required for work connected with the fundamental aspects of the operation of microwave valves. Apply in writing to the Staff Manager (Ref. RLO/259), **Research Laboratories of the General Electric Co. Ltd., North Wembley,** Middlesex, giving details of age, qualifications and experience.

Physicists and **Engineers** required by **Ministry of Supply, R.A.E., Farnborough,** Hants, Instrument and Photographic Department. Post 1 (Ref. A.247/53/A) Scientific Officer for research and development in connection with gyroscopic and allied instruments. Some related experience and practical knowledge of electronics desirable. Considerable scope for inventive ability. 1st or 2nd class honours degree or equivalent in Physics or Engineering required. Salary within range £417 – £781. F.S.S.U. benefits may be available. Posts 2 and 3 (Ref. A.248/53/A), Experimental Officer (E.O.) or Assistant E.O. to assist in above duties. Practical experience of development in light mechanical or electro-mechanical field desirable. Post 4 (Ref. A.249/53/A) E.O. for research and development mainly in photographic optics. Experience in the manufacture and testing of photographic lenses and optical equipment desirable. E.O. Class minimum qualification :—Higher School Cert. (Science) or equivalent but H.N.C. or degree in Physics or Engineering may be an advantage. Salary within ranges :—E.O. (min. age 26), £649 – £799, or Asst. E.O., £264 (age 18) – £576. All appointments unestablished. Rates for women somewhat lower. Application forms from M.L.N.S., Technical and Scientific Register (K), 26 King Street, London, S.W.1, quoting appropriate reference.

Research Scientist required for research on domestic heating. Applicant should have B.Sc., preferably in Physics. Age 26 – 34. Starting salary £600 – £800. Previous research experience in fuel technology and/or instruments an advantage. Pension scheme. Apply in writing to Assistant Secretary, Ref. A.37, **British Coal Utilisation Research Association,** Randalls Road, **Leatherhead,** Surrey.

Ministry of Supply requires **Physicists** or **Mathematicians** for following posts at Atomic Weapons Research Establishment, Fort Halstead, Kent. **Senior Scientific Officers** or **Scientific Officers** (Ref. A.258/53/A) :—(1) To lead small team engaged in analysis of photographic observations. To be responsible for both measurement and interpretation of records and to carry out research on methods of obtaining maximum information from existing photographic instruments. Experience in use of statistical methods an advantage. (2) To take charge of optical laboratory and to undertake optical design associated with high speed photographic systems. Qualifications :—1st or 2nd class Hons. degree or equivalent in physics or maths. For post 2 additional qualifications in optical theory may be an advantage. Salary within ranges, S.S.O. (min. age 26 and at least 3 years post-grad. research experience), £875 – £1,033, or S.O., £417 – £781. F.S.S.U. benefits may be available. **Assistant Experimental Officer** (Ref. A.259/53/A) :—To measure and assess photographic records, and for practical work connected with calibration of photographic instruments. Qualifications :—minimum of Higher School Cert. (science) or equivalent. Pass degree in physics may be an advantage, and knowledge of statistical methods or sensitometry, or experience in use of optical measuring instruments, desirable. Salary within range, £264 (age 18) – £576. All appointments unestablished. Rates for women somewhat less. Application forms from M.L.N.S., Technical and Scientific Register (K), 26 King Street, London, S.W.1, quoting appropriate reference. Closing date November 24, 1953.

Ferranti Limited, Manchester, have staff vacancies in connection with transistor development at their new laboratories at Wythenshawe, South Manchester.

(I) **Engineers** and **Physicists** are required for fundamental work on semiconductors and transistors and for work on transistor manufacturing techniques. Qualifications Required : 1st or 2nd Class Hons. degree in physics, electrical engineering or metallurgy ; experience in a relevant field is required for the more senior posts. Salary according to qualifications and experience in the range of £500 – £1,500 per annum.

Please quote ref. P.D.H.(I).

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Application forms from Mr. R. J. Hebbert, Staff Manager, Ferranti Ltd., Hollinwood, Lancs.

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